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Multifunctional backup electricity supply for NPP auxiliary needs based on combined-cycle power plant with hydrogen overheating

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Abstract

Approach is suggested of combining nuclear power plant with combined cycle gas turbine unit and hydrogen producing complex which, while operated in normal conditions, give the possibility to increase plant capacity and, in case of complete blackout, to ensure supply of electricity for covering auxiliary needs of the NPP. It is suggested to use hydrogen for overheating generated steam by exhaust gases of the gas turbine plant included in the composition of the combined cycle gas turbine unit. Combined cycle gas turbine unit must be installed beyond the NPP site. Hydrogen is to be generated by electrolysis of water using cheap off-peak energy produced by the NPP during nighttime, following which hydrogen will be efficiently used during the day for enhancing parameters of steam before the gas turbine included in the composition of the combined cycle gas turbine unit.

Probabilistic assessment was performed of reliability of the proposed system in the conditions of loss of power supply for the case of joint use of the combined cycle gas turbine unit and emergency electric power supply channels equipped with diesel generators.

The proposed system allows ensuring supply of electricity for covering auxiliary needs of the NPP during more than 72 h. Use of the steam turbine plant included in the composition of the combined cycle gas turbine unit is possible for covering auxiliary needs of the NPP in case of failure of gas turbine plants. Steam turbine can be operated due to the generation of additional steam during incineration of hydrogen in oxygen. With appropriate modernization the system allows using decay heat released in the nuclear reactor core. It was established that the proposed option of combining NPP with combined cycle gas turbine unit in combination with hydrogen generating complex allows enhancing reliability of supply of electricity for covering auxiliary needs of the NPP in emergency conditions accompanied with loss of electric power supply.

Keywords: Emergency electricity supply; Hydrogen cycle; Combustion chamber; Nuclear power plant; Combined cycle gas turbine unit; Maneuverability; Safety; Back-up electricity supply for covering auxiliary needs of the NPP; Nuclear emergency with complete loss of electric power supply.

Introduction

There exist a number of systems based on the use of hydrogen generating complex intended for enhancement of NPP power output, as well as for ensuring supply of electricity for covering auxiliary needs of the nuclear power plant in case of emergency situation accompanied with loss of electricity supply [1–4]. All the proposed systems imply the use of hydrogen incorporated in the NPP cycle. In the conditions of special attention paid to the safety of nuclear power plants a number of scientists and political activists assume strongly negative attitude to the use of hydrogen on the nuclear power plant site. Generation of hydrogen by NPP with, at the same time, the use of the generated hydrogen on the satellite plant located off-site may become and alternative option. Steam superheaters operated with hydrogen combustion are known [5], but, however, all of them have the same pronounced drawback, namely, the need of continuous water cooling resulting in the reduction of efficiency of use of high-temperature heat released from products of hydrogen combustion in oxygen

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because of the need to remove significant amounts of heat for changing physical state of ballasting water. Besides that, salt depositions are formed on the lines of external cooling of the combustion chamber with ballasting water which becomes with time the cause of loss of functionality of hydrogen combustion steam superheater.

Alternative use of hydrogen is suggested for superheating steam generated by exhaust gases of gas turbine plant (GTP) included in the composition of the combined cycle gas turbine unit (CCGTU) which is to be located off the NPP site. Hydrogen is to be generated via electrolysis of water using cheap off-peak electric power generated by the NPP and will be efficiently utilized improving parameters of steam before entering the steam turbine included in the composition of the CCGTP [6].

Such arrangement will ensure reliable backup electricity supply for covering auxiliary needs (AN) of the nuclear power plant in case of emergency situations associated with complete loss of electricity supply. Practical importance of the proposed solution is confirmed as well by the Fukushima-1 NPP accident which demonstrated that efficiency and reliability of existing emergency protection systems on the basis of stand-by electrical diesel generators does not satisfy contemporary safety requirements for NPPs. There exist projects aimed at enhancement of safety which are mainly based on passive heat removal systems (PHRS) or on the arrangement of additional channel of emergency electricity supply system (EESS) with diesel generator (DG). However, installation of PHRS or EESS with DG equipment increases the value of NPP fixed assets without increasing the output of electricity by the NPP which adversely affects competitiveness of the nuclear power plant.

Theoretical background

According to the proposed system of multifunctional backing up of electricity supply for coverage of AN of NPPs on the basis of combined cycle gas turbine unit using steam superheating by hydrogen combustion, supply of electricity to consumers of the first group (CPS, safety control systems, emergency lighting) and the second group (pumps of the emergency core cooling system, emergency electric fee pump) can be provided due to the incorporation of additional combined cycle gas turbine unit (CCGTU) with incorporated steam superheating by hydrogen combustion. Circulation pump of steam condenser required for preservation of the working medium by the discharge of steam generated in steam generators (SG) in the steam condenser through the quick-action pressure reduction unit (BRU-K) must remain in operation. CCGTP consisting of two gas turbine and one steam turbine plants was examined.

The system operation (Fig. 1) is as follows. During off-peak night hours GTP 4 and STU 8 reduce their load but remain in operation performing the role of hot standby. Accumulation of electric power not consumed during night hours takes place in the process of water electrolysis in the form of

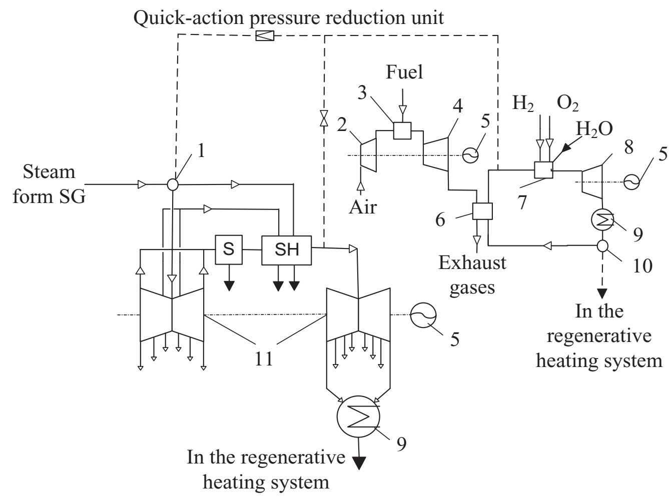

Fig. 1. Schematic process layout of the system of multifunctional backing up of electricity supply for covering AN of the NPP on the basis of combination with CCGTP and utilization of steam superheating by hydrogen combustion: 1: steam distribution device; 2: compressor; 3: combustion chamber; 4: GTP; 5: electric generators; 6: utilizing boiler; 7: two-stage combustion chamber with combined steam-water cooling; 8: STU; 9: condensers; 10: condensate distribution device; 11: main STU.

stock of hydrogen and oxygen which are directed to storage cylinders using hydrogen and oxygen booster stations.

During the hours of peak electric load GTP generates electric power. Steam is generated in the utilizing boiler 6 using the exhaust gases, it is superheated due to the combustion of accumulated hydrogen in oxygen inside the two-stage combustion chamber with combined steam-water cooling 7 [7] and is directed to the STU which also generates electricity.

Application of two-stage combustion chamber with combined steam-water cooling 7 ensures efficient use of energy accumulated in the form of hydrogen and oxygen. High-temperature steam produced using the combustion chamber with combined steam-water cooling is mixed with steam generated in the utilizing boiler 6, which results in the increase of steam temperature and in the increased heat drop and steam flow rate in the STU [8].

In case of emergency situation accompanied with complete loss of electricity supply to the nuclear power plant GTPs are operated producing electricity required for consumers of the first and the second categories and for the NPP circulation pump. Dual redundancy is achieved in this case, because one GTP is capable standing alone to generate electric power required for decay heat removal from NPP reactors. In case of GTP failure steam is generated by the two-stage combustion chamber with combined steam-water cooling where the stock of hydrogen and oxygen accumulated in the back-up storage system is supplied through stand-by receivers and where ballasting water is injected. Ballasting water ensures cooling of the combustion chamber and steam generation in the volumes required for provision of electric power for coverage of auxiliary needs of the NPP using the STU.

Steam line can be arranged from steam generator to the CCGTP for safety enhancement (steam line length is from